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In a recent paper [1] it was shown that the intensity of the sun's radiation, as it is outside the earth's atmosphere, varies simultaneously in 23 regular periods, all aliquot parts of approximately 272 months. It would naturally follow that details of variation in observed values of the solar constant of radiation would tend to repeat at intervals of about 23 years. Figure 4A of the paper cited shows that this is indeed the case.

Many years ago it was shown that the precipitation at Peoria, Ill., also tended very strongly to exhibit repetitions of features at intervals of 23 years. I reproduce here as figure 1, the figure 33 of an earlier paper.[2]

Intending to trace the effect of the solar variations above noted on weather, it seemed well to study first the records of precipitation at Peoria, as these were already known to exhibit influences of the master cycle of about 23 years. I have been engaged over 3 years in this investigation, for unexpected complexities kept cropping up, which made it necessary again and again to scrap all results and begin at the beginning. Without being tedious, it may be said that I have tabulated over 1,000 months of precipitation records, of the years between 1856 and 1939, separately in 20 to 30 supposed periods, and repeated the whole tabulation no less than 14 times.

Futility of determining periods from weather records.—Knowing that the sun's radiation varies in regular periods, which are integral submultiples of about 23 years, but being restricted by available solar-constant observations to little more than 20 years with many gaps and inaccuracies in these records, I hoped at first to use the continuous series of Peoria precipitation records from 1856 to 1939 to establish which submultiples of 23 years are active, and to fix their exact lengths.

[1] Smithsonian Misc. Coll., vol. 117, No. 10, 1952.
[2] Smithsonian Misc. Coll., vol. 94, No. 10, 1935.

It was soon disclosed that the phases of periodicities, though invariable in solar variation, shifted in Peoria precipitation records, depending on the time of the year. I suppose the cause to be associated with considerations of lag in response to solar impulses. It is patent that though the sun's heating potential reaches a maximum daily at noon, maximum temperatures do not come until several hours after noon, and their arrival displays different lags in different localities, and in the same locality at different times and seasons. Similar it must be with regard to all weather responses to all solar periodicities.

Subdivision of the year.—Accordingly, one of my first modifications of procedure was to prepare separate tabulations for each periodicity in three fractions of the year, namely: January to April, May to August, September to December. Doubtless a finer subdivision of the year would theoretically be better, but for periodicities of 10 to 20 months in length the number of columns in a tabulation becomes few.

Interference between periodic effects.—It is plain that the determination of every periodic fluctuation in precipitation must be affected by the presence, implicitly in the data, of above 20 other periods of different lengths. Theoretically these disturbing influences can only be completely sifted out of the result for one period, if the mean values are computed from an infinite number of repetitions of the chosen period. When, instead of infinity, one becomes limited to a few repetitions, the computed march of the investigated periodicity must evidently be very imperfectly determined. Hence, on account of paucity of data, it was impracticable to divide the years beyond the triple division mentioned above.

Sunspot frequency affects phases.—But still another limitation of freedom in tabulation soon appeared. The phases of features in the periodicities computed were found different in different years. This was found to be associated with sunspot frequency. As said above, the cause of the phenomena of phase changes is probably to be assigned to variable lag of response in weather to solar impulses, depending on the condition of the atmosphere. Such changes in lag are evidently attributable to the varying character of the atmosphere at different seasons of the year as regards transparency, cloudiness, and other conditions. But sunspots continually bombard the atmosphere with multitudes of electric ions. These act as centers of condensation for the constituents of haze. Hence it was only to be expected that phase changes would be associated with Wolf sunspot numbers. Here, again, a compromise had to be made. It was decided to subdivide the precipitation data in two groups, for Wolf numbers $\gtrless 20$.

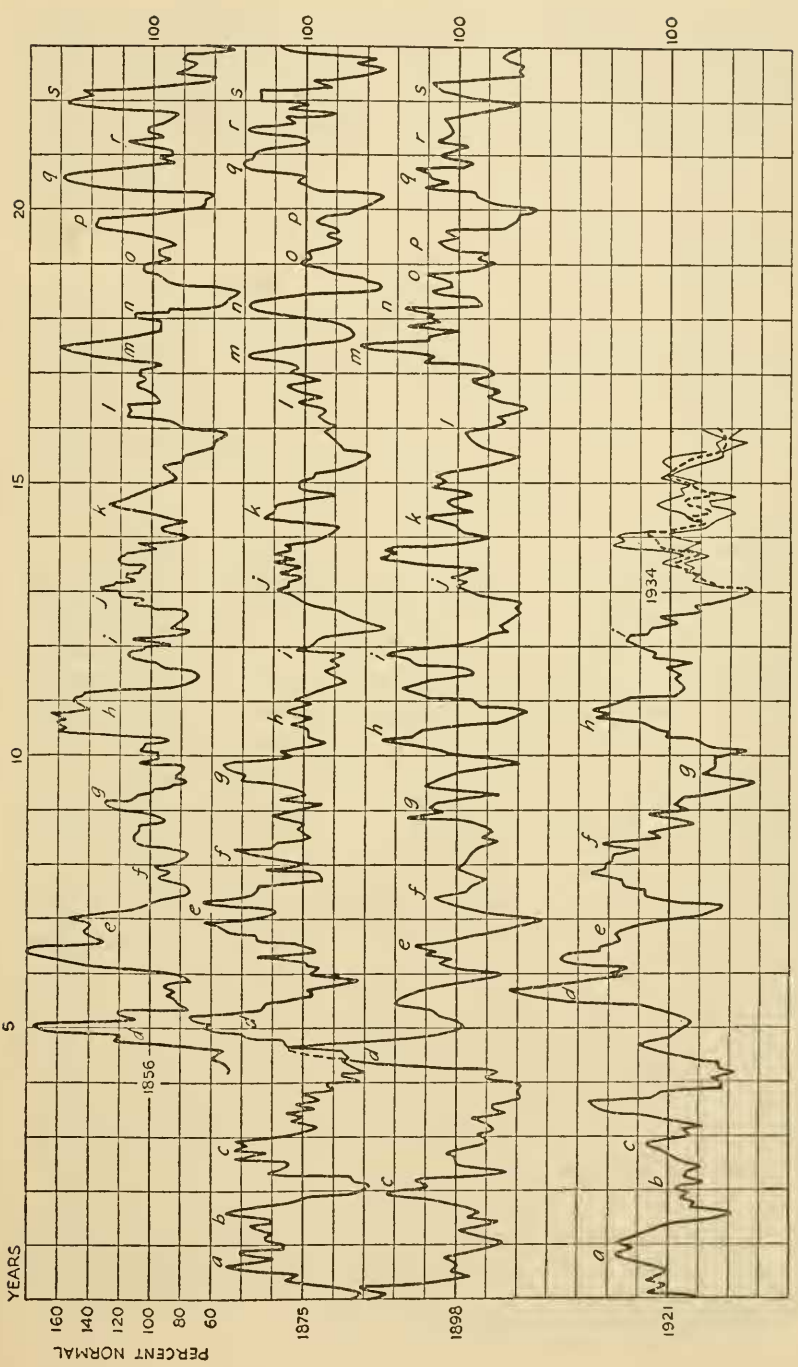


FIG. 1.—Twenty-three-year periodicity in Peoria precipitation.

Necessary roughness of determinations.—Between the accidental influences associated with rainfall, cloudiness, haziness, etc., the undeterminable interferences of some 20 periodic solar variations on the periodicity being considered, and the necessary subdivision of the data for seasonal and sunspot alterations of atmospheric quality, the determinations of periodicities in precipitation became too rough to warrant conclusions that such and such submultiples of 23 years were real, effective periods in solar variations.

Length and number of periods necessarily determined from solar observations.—Thrust back on the solar-constant observations as the only sound source of knowledge of the solar periods, I laid aside the investigation of Peoria precipitation to prepare the paper above cited (footnote 1). In that paper are listed 23 periods that appear to be real in solar variation, and 15 others that were tried and found wanting. In the latter part of the Peoria tabulations the investigation was limited to the confirmed 23 periods. However, for convenience in tabulating, the lengths of some periods were slightly altered.

Faulty normals.—Still another unsuspected hitch occurred in the investigation, which caused several weeks delay and a completely new tabulation of the precipitation data. This is explained in another recent paper.[3] In substance it amounts to this: The monthly normal values printed at the bottom of the pages in World Weather Records [4] make no distinction between times of sunspot maximum and times of sunspot minimum. Two consequences result. First, the average of the monthly data computed as percentages of the published normals of precipitation at Peoria is about 9 percent higher for times when Wolf sunspot numbers exceed 20 than for times when these Wolf numbers are below 20. Second, far more serious, and indeed fatal to success in my investigations made theretofore, is the fact that when averages of data timed for sunspots $\gtrless 20$ are separated, there is found a large discrepancy, month by month, between these averages for Wolf numbers <20 and for Wolf numbers >20. This plays havoc with tabulations of periodicity. The published normals, in fact, combine two contradicting sets of data as foreign to each other in attitude as dogs are from cats, and tabulations including both sorts in the same periodicity are worthless.

Final preparation of the data.—The recorded monthly values of precipitation at Peoria for the years 1856 to 1950, found in World Weather Records and later publications, were segregated in two

[3] Smithsonian Misc. Coll., vol. 117, No. 11, 1952.
[4] Smithsonian Misc. Coll., vols. 79, 90, and 105.

groups, for Wolf numbers $\gtrless 20$. Monthly normal values were computed separately, 52 years in the high-sunspot group, 30 years in the other. Two years were omitted, when the months were about evenly divided between the two classes.

The new normals for Peoria precipitation, as expressed in inches, are as follows:

Sunspots	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
>20	1.84	1.87	2.80	3.62	3.90	4.04	3.70	3.06	3.56	2.22	2.36	1.91
<20	1.58	1.71	2.82	2.79	3.88	3.24	3.40	2.66	3.85	2.56	2.22	1.88

From these new normals percentages of normal precipitation were computed for every month, 1856 to 1950. There are such large and suddenly changing jumps from month to month in these percentages of normals that the data were then smoothed by 5-month consecutive means. Thus, for March compute

$$\frac{\text{Jan.}+\text{Feb.}+\text{Mar.}+\text{Apr.}+\text{May}}{5}.$$

For April drop January and add June, and so on. Even then, as some exceptionally rainy months occurred, the smoothed data would soar above 200 percent for a brief interval. With the necessarily few columns in a tabulation, such an exceptional case might quite vitiate the determination of a periodicity. Hence for some 20 exceptional months out of over 1,000, the original values were scaled down to 200 before the smoothing process was done.

Division of the interval.—While the number and lengths of the periodicities to be sought in Peoria precipitation had been fixed by study of solar-constant observations, and nothing was to be learned as to the reality or the exact length of these periodicities in solar radiation from the precipitation data, it still was desirable to tabulate Peoria precipitation in several parts independently. Certain of the solar periodicities might produce such weak responses in precipitation that the several groups might give no agreeing results distinguishable from accidental error. Such weak periodic effects could be neglected. Such indeed proved to be the case with periods of $2\frac{1}{7}$ and $3\frac{1}{15}$ months, and with the periodicity of 68 months. There were strong features in the separate determinations of the periodicity of 68 months, but they were so confused by overriding interference from various shorter periods as to be uncertain. Hence that period was dropped.

More important, however, just as the changing atmospheric conditions were found to alter phases with the seasons, and with the prevalence of sunspots, it proved that, apart from these already noted

phase alterations, there were secular changes of phases. One group of years, though yielding the same forms of periodicities as another, yielded them in different phases. Such effects were found to vary in character for periods of different lengths.

In the tabulations, therefore, the years 1856 to 1900 were tabulated separately from the years 1900 to 1939. Discordant phases appearing in the earlier interval were shifted to accord with the phases for the years 1900 to 1939. Then the two determinations were averaged together. So the full strength of the data from 1856 to 1939 was concentrated in the phases prevailing from 1900 to 1939.

Fractional months in periods.—In order to preserve the exact period in such cases as $9\frac{1}{6}$, $11\frac{1}{3}$, and $15\frac{1}{6}$ months, and others not exactly even months in length, some columns in tabulating were made a month longer or a month shorter than others. In case of long periods, months were interpolated or cut out of the columns from place to place as required to make the average length of the columns equal to the period. Such additions to columns may be noted in tables 1 and 2 for the $9\frac{1}{6}$-month periodicity, and in tables 3 and 4 for $15\frac{1}{6}$ months.

Examples of tabulation.—In order to fix ideas, I now give two actual tabulations and corresponding plots, to bring out the process employed, and to clarify the explanations above. I select the periods of $9\frac{1}{6}$ and $15\frac{1}{6}$ months. Table 1 gives the tabulation for $9\frac{1}{6}$ months suited to Wolf numbers >20, and table 2 that for Wolf numbers <20. In each table the segregation of the year by 4-month intervals is preserved. Also, two separate tables for each 4-month interval are made, one for the first half, the other for the last half of the 84-year interval. As stated above, there is often found a discrepancy in phase between results of the first and second halves of the 84-year interval. In table 1, sections A_1 and B_1, the symbol $A_1\uparrow_1$ means that to bring the phase of the first half, A_1, to that of the second half, B_1, the mean values for A_1 are moved one month backward. The symbol $A_2\uparrow_2$ obtains in sections A_2 and B_2, and $A_3\downarrow_3$ was required for sections A_3 and B_3. Similar symbols for shifts appear in the tabulation of the data suited to Wolf numbers <20. The final columns, marked Δ, give the departures from the average percentage of results in the general means. The use of these columns of departures will be explained below.

Tables 3 and 4, relating to the periodicity of $15\frac{1}{6}$ months, will be understood from the preceding description of tables 1 and 2 for $9\frac{1}{6}$ months. As before, symbols involving $\uparrow$ mean that the means of the first half of the data were shifted backward by one or more months, and symbols involving $\downarrow$ indicate the contrary.

TABLE 1.—*Peoria precipitation. The 9½-month period*

Sunspots > 20

A_1											
Jan. '59	Feb. '62	Mar. '65	Jan. '69	Apr. '71	Jan. '72	Mar. '81	Apr. '84	Jan. '85	Feb. '91	Mar. '68	Mean
149	103	105	108	82	67	96	111	106	82	113	102.0
124	101	112	90	86	67	126	97	112	88	111	101.3
102	80	101	102	95	56	101	109	87	86	111	93.9
96	113	99	127	118	90	85	127	79	91	91	105.0
84	135	118	139	139	124	99	140	90	99	98	115.0
72	135	121	149	139	135	122	139	91	90	71	114.9
74	142	115	133	139	142	122	153	96	86	102	118.5
77	139	95	116	109	137	146	154	108	105	113	118.5
87	142	109	106	79	118	151	131	97	115	106	112.9
96									91	109	

B_1											
Mar. '94	Feb. '04	Mar. '07	Feb. '17	Apr. '26	Jan. '27	Mar. '36	Apr. '39	Mean	$A_1 \uparrow_1$	Mean	Δ
96	93	84	83	96	133	67	153	98.1	101.3	99.7	− 5.9
89	106	64	77	103	121	50	128	92.3	93.9	93.1	−12.5
79	98	89	93	126	149	39	121	99.2	105.0	102.1	− 3.5
73	94	113	100	155	158	41	97	103.9	115.0	109.4	+ 3.8
86	89	114	106	167	155	75	108	112.5	114.9	113.7	+ 8.1
80	107	106	98	178	132	97	90	111.0	118.5	114.7	+ 9.1
84	87	101	106	158	137	104	71	106.0	118.5	112.2	+ 6.2
95	76	92	70	136	135	132	64	100.0	112.7	106.4	+ 0.8
93	80	58	68	124	135	148	69	96.9	102.0	99.5	− 6.1
									Mean	105.6	

A_2										
Aug. '60	May '61	Aug. '63	June '64	July '70	Aug. '73	May '74	July '83	June '93	July '96	Mean
99	91	92	75	57	87	54	95	84	136	87.0
101	81	96	55	87	84	83	93	66	109	85.5
93	74	113	79	93	104	76	107	49	116	90.4
91	84	114	98	102	129	79	102	58	83	94.0
105	82	104	115	107	124	88	106	63	91	98.5
127	76	85	107	104	111	80	124	89	77	98.0
128	100	105	122	89	115	47	107	87	108	100.0
107	87	72	114	93	85	65	86	103	105	91.5
105	85	69	125	91	62	70	100	96	108	91.1
		80								

B_2														
June '06	June '09	Aug. '15	May '16	Aug. '18	June '19	July '25	Aug. '28	May '29	June '35	July '38	Mean	$A_2 \uparrow_2$	Mean	Δ
70	101	111	63	117	100	101	131	137	109	129	106.3	90.4	98.3	+0.1
82	87	120	86	120	106	116	132	124	112	107	108.4	94.0	101.2	+3.0
77	109	100	98	131	106	123	135	101	86	87	105.1	98.5	101.8	+3.6
82	131	108	106	93	111	112	150	113	88	68	105.6	98.0	101.8	+3.6
85	132	84	109	109	98	99	138	106	88	85	103.0	100.0	101.5	+3.3
114	152	95	121	114	78	96	138	86	101	104	109.0	91.5	100.2	+2.0
88	149	85	102	100	61	92	130	97	100	120	102.6	91.1	96.8	−1.4
95	107	86	84	90	81	84	129	114	98	135	100.3	87.0	93.6	−4.6
90	93	60	73	109	89	83	112	90	73	143	92.3	85.5	88.9	−9.3
	90			101								Mean	98.2	

A_3										
Nov. '59	Nov. '62	Oct. '69	Oct. '72	Dec. '81	Oct. '82	Oct. '85	Dec. '91	Sept. '92	Dec. '94	Mean
89	132	94	88	162	88	102	99	69	72	99.5
98	137	94	96	143	91	91	110	70	67	99.7
87	142	94	87	121	92	81	100	78	58	94.0
76	135	111	89	116	126	77	115	96	57	99.8
73	107	87	98	139	98	83	131	107	45	96.8
77	79	68	112	120	114	72	129	119	82	97.2
92	70	49	89	110	129	84	116	124	89	95.2
100	66	49	98	105	136	67	104	120	101	95.6
103	72	39	97	106	114	72	75	103	98	87.9
			91	88						

B_3														
Sept. '95	Nov. '04	Sept. '05	Dec. '07	Sept. '08	Nov. '14	Nov. '17	Oct. '24	Oct. '27	Dec. '36	Oct. '37	Mean	$A_3 \downarrow_3$	Mean	Δ
125	66	88	83	67	88	62	106	140	132	73	93.6	95.2	94.4	−1.4
127	44	81	98	54	88	63	65	134	109	102	87.7	95.6	91.7	−4.1
126	57	91	106	53	76	50	67	120	123	119	89.8	87.9	88.8	−7.0
119	78	101	129	67	83	69	67	99	106	127	95.0	99.5	97.2	+1.4
121	87	94	142	74	103	77	72	76	99	137	98.4	99.7	99.0	+3.2
110	100	88	122	93	93	83	54	62	85	145	94.1	94.0	94.0	−1.8
96	108	86	122	103	102	84	64	90	88	139	98.4	99.8	99.1	+3.3
93	102	84	104	104	128	116	65	95	70	150	101.0	96.8	98.9	+3.1
111	90	78	71	109	146	105	82	112	78	138	101.8	97.2	99.5	+3.7
134	92							114				Mean	95.8	

TABLE 2.—*Peoria precipitation. The 9⅙-month period*

Sunspots < 20

A_1

Apr. '58	Feb. '75	Mar. '78	Feb. '88	Apr. '97	Jan. '98	Apr. '00	Feb. '01	Mar. '65	Mean
148	65	97	119	79	157	101	80	105	105.7
159	80	115	115	92	159	58	84	112	108.2
156	95	104	102	65	165	88	85	101	106.8
139	113	123	121	54	140	96	94	99	108.8
127	106	101	110	48	113	90	73	118	98.4
137	132	109	126	67	98	98	81	121	107.4
144	137	93	109	54	108	100	81	115	104.6
138	125	100	122	93	103	84	61	95	102.3
138	106	80	110	118	100	85	62	109	100.9
						93			

A_2

July '57	June '67	Aug. '76	May '77	June '80	July '86	May '87	Aug. '89	May '90	Mean
84	85	154	120	118	83	50	125	69	98.7
88	76	139	112	103	85	64	111	68	94.0
86	62	110	106	85	78	67	81	62	81.9
94	62	98	129	88	85	77	107	75	90.6
74	59	75	127	81	77	82	110	76	84.6
82	50	63	136	65	97	104	111	77	87.2
88	55	59	127	85	87	107	102	77	87.4
111	85	70	138	95	86	113	102	86	96.2
135	85	103	117	87	83	125	81	78	99.3
			111		79				

A_3

Dec. '65	Sept. '66	Nov. '75	Dec. '78	Sept. '79	Nov. '88	Oct. '98	Mean
80	121	132	86	112	114	107	107.5
83	112	116	68	112	99	92	97.5
99	100	122	81	135	92	84	101.9
104	100	116	64	158	87	82	101.5
79	90	129	70	164	82	73	98.2
97	97	134	79	155	100	94	108.0
109	98	143	80	170	135	101	119.4
124	98	134	78	144	134	88	114.3
133	80	138	90	119	128	76	109.1

B_1

Jan. '11	Apr. '13	Jan. '14	Mar. '20	Mar. '23	Jan. '24	Feb. '30	Mar. '33	Apr. '10	Mean	$A_1 \downarrow_4$	Mean	Δ
97	110	85	102	93	92	86	132	70	96.3	107.4	101.3	+4.4
109	77	75	102	92	95	87	118	76	92.3	104.6	98.4	+1.5
101	74	79	108	91	81	71	114	78	88.6	102.3	95.4	−1.5
112	62	69	81	83	105	54	101	68	81.8	100.9	91.3	−5.6
99	77	58	57	96	119	53	110	58	80.8	105.7	93.2	−3.7
94	87	65	59	100	150	41	87	61	82.7	108.2	95.4	−1.5
114	92	79	59	99	154	63	82	55	88.6	106.8	97.7	+0.8
129	95	84	70	114	154	79	83	80	98.7	108.8	103.7	+6.8
115	97	70	75	115	114	76	76	91	92.1	98.4	95.7	−1.2
		85		107						Mean	96.9	

B_2

July '99	Aug. '02	May '03	July '12	June '22	Aug. '31	May '32	Mean	$A_2 \downarrow_2$	Mean	Δ
94	188	113	95	79	118	80	109.6	96.2	102.9	+3.5
84	176	127	103	67	145	86	112.5	99.3	105.9	+6.5
89	153	132	106	60	134	81	107.9	98.7	103.3	+3.9
101	122	129	88	86	147	87	108.5	94.0	101.2	+1.8
116	101	126	103	83	138	86	107.5	81.9	94.7	−4.7
134	94	110	120	92	131	113	113.4	90.6	102.0	+2.6
123	98	89	113	87	104	111	103.6	84.6	94.1	−5.3
110	104	70	124	100	99	118	103.6	87.2	95.4	−4.0
116	105	83	122	81	76	126	101.3	87.4	94.3	−5.1
						140		Mean	99.4	

B_3

Nov. '01	Oct. '11	Dec. '20	Sept. '21	Nov. '30	Dec. '33	Sept. '34	Mean	A_3	Mean	Δ
59	123	68	126	72	55	141	92.0	107.5	99.6	− 5.8
60	114	86	139	75	50	123	92.4	97.5	95.0	−10.4
92	89	121	131	64	56	127	97.2	101.9	99.7	− 5.7
98	83	112	129	53	45	123	91.9	101.5	96.7	− 8.7
89	101	108	142	77	50	132	99.9	98.2	99.0	− 6.4
118	101	122	137	85	73	105	105.9	108.0	107.0	+ 1.6
143	108	116	130	110	77	130	116.3	119.4	117.8	+12.4
144	124	96	115	111	103	142	119.3	114.3	116.8	+11.4
170	122	108	110	120	113	126	124.4	109.1	116.7	+11.3
								Mean	105.4	

TABLE 3.—*Peoria precipitation. The* $15\frac{1}{5}$*-month period*

Sunspots > 20

			A_1								B_1					
Feb. '59	Mar. '64	Apr. '69	Jan. '73	Feb. '83	Jan. '92	Mean	Apr. '93	Mar. '07	Jan. '16	Apr. '17	Feb. '26	Apr. '36	Mean	$A_1\downarrow_5$	Mean	Δ
24	72	127	89	114	110	106.0	120	84	95	93	84	50	87.7	105.0	96.3	— 2.0
02	69	139	98	129	100	106.2	103	64	85	100	83	39	79.0	101.2	90.1	— 8.1
96	80	149	112	136	115	114.7	84	89	86	106	96	41	83.7	89.0	86.3	—12.0
84	75	133	89	114	131	104.3	66	113	60	98	103	75	85.8	94.7	89.7	— 8.6
72	55	116	98	112	129	97.0	49	114	63	106	126	97	92.5	89.5	91.0	— 7.3
74	79	106	97	95	116	94.5	58	106	86	70	155	104	96.5	106.0	101.2	+ 2.9
77	98	94	91	93	104	93.0	63	101	98	68	167	132	104.8	106.2	105.5	+ 7.2
87	115	94	87	107	75	94.2	89	92	106	62	178	148	112.5	114.7	113.6	+15.3
96	107	94	84	102	69	92.0	87	58	109	63	158	132	101.2	104.3	102.7	+ 4.4
89	102	111	104	106	70	97.0	103	83	121	50	136	109	100.3	97.0	98.6	+ 0.3
98	114	87	129	124	78	105.0	96	98	102	69	124	123	102.0	94.5	98.3	0.0
87	125	68	124	107	96	101.2	96	106	84	77	133	106	100.3	93.0	96.7	— 1.6
76	105	49	111	86	107	89.0	89	129	73	83	121	99	99.0	94.2	96.6	— 1.7
73	112	49	115	100	119	94.7	79	142	83	84	149	85	103.7	92.0	97.8	— 0.5
77	101	39	85	111	124	89.5	73	122	77	116	158	88	105.7	97.0	101.3	+ 3.0
				97										Mean	98.3	

			A_2								B_2				
May '60	July '70	June '84	July '94	May '03	Mean	Aug. '04	June '08	May '27	Aug. '28	July '37	July '18	Mean	$A_2\downarrow_5$	Mean	Δ
92	57	109	86	113	91.4	87	122	155	131	70	105	111.7	92.0	101.8	— 0.2
100	87	127	80	127	104.2	76	104	132	132	78	117	106.5	95.4	100.9	— 1.1
103	93	140	84	132	110.4	80	71	137	135	64	120	101.2	99.0	100.1	— 1.9
99	102	139	95	129	112.8	66	67	135	150	73	131	103.7	104.6	104.1	+ 2.1
101	107	153	93	126	116.0	44	54	135	138	102	93	94.3	110.6	102.4	+ 0.4
93	104	154	72	110	106.6	57	53	135	138	110	109	100.3	91.4	95.8	— 6.2
91	89	131	67	89	93.4	78	67	140	130	127	114	109.3	104.2	106.7	+ 4.7
105	93	106	58	70	86.4	87	74	134	129	137	100	110.2	110.4	110.3	+ 8.3
127	91	112	51	83	92.8	100	93	120	112	145	90	110.0	112.8	107.8	+ 5.8
128	82	87	45	93	87.0	108	103	89	137	139	109	109.5	116.6	113.0	+11.0
107	86	79	82	106	92.0	102	104	76	124	150	101	109.5	106.6	108.0	+ 6.0
105	95	90	89	98	95.4	90	109	62	104	138	100	100.5	93.4	96.9	— 5.1
91	118	91	101	94	99.0	92	101	90	113	129	106	105.2	86.4	95.7	— 6.3
81	159	96	98	89	104.6	88	87	95	106	107	111	99.0	92.8	95.9	— 6.1
74	139	108	125	107	110.6	81	109	112	86	87	98	95.5	87.0	91.3	—10.7
84									97				Mean	102.0	

			A_3								B_3					
Nov. '57	Sept. '61	Dec. '62	Dec. '67	Oct. '71	Nov. '81	Sept. '90	Mean	Oct. '95	Nov. '05	Oct. '14	Oct. '19	Nov. '24	Dec. '34	Oct. '38	Mean	$A_3\uparrow_5$	Mean	Δ
74	82	137	55	139	151	76	102.0	127	91	85	98	65	123	68	93.9	101.3	97.6	— 3.
82	76	142	85	109	162	77	104.7	126	101	88	78	67	132	85	95.3	102.1	98.7	— 2.
88	100	135	85	79	143	77	101.0	119	94	88	61	67	105	104	91.1	103.7	97.4	— 3.
111	87	107	113	67	121	86	98.9	121	88	76	81	72	130	120	98.3	105.9	102.1	+ 1.
135	85	79	111	67	116	78	94.4	110	86	83	89	54	142	135	99.9	115.3	107.6	+ 6.
148	103	70	111	56	139	82	101.3	96	84	103	102	64	126	143	102.6	116.1	109.3	+ 8.
159	101	66	91	90	120	88	102.1	93	78	93	102	65	109	133	94.7	114.4	104.5	+ 3.
156	80	72	98	124	110	86	103 7	111	70	102	108	82	112	128	101.9	109.4	105.6	+ 5.
139	113	92	71	135	105	81	105.1	134	82	128	81	101	86	121	105.6	115.7	110.6	+ 9.
127	135	96	102	142	106	99	115.3	136	77	146	57	116	88	97	102.4	109.7	106.0	+ 4.
137	135	113	113	137	88	90	116.1	109	82	111	59	123	88	108	97.1	102.0	99.6	— 1.
144	142	114	106	118	91	86	114.4	116	85	120	59	112	101	90	97.6	104.7	101.0	— 0.
138	139	104	100	88	92	105	109.4	83	114	100	70	99	100	71	91.0	101.0	96.0	— 5.
138	142	85	108	96	126	115	115.7	91	88	108	75	96	98	64	88.6	98.9	93.7	— 7.
149	132	105	90	87	98	91	109.7	77	95	84	68	92	73	69	79.7	94.4	87.0	—14.
			102			99			90				67			Mean	101.1	

Graphical presentation.—The results on the $9\frac{1}{6}$-month periodicity, in tables 1 and 2, are shown graphically in figures 2 and 3. In each of the six charts shown in each figure, the lower curve (*a*), in light

TABLE 4.—*Peoria precipitation. The* $15\frac{1}{6}$*-month period*

Sunspots < 20

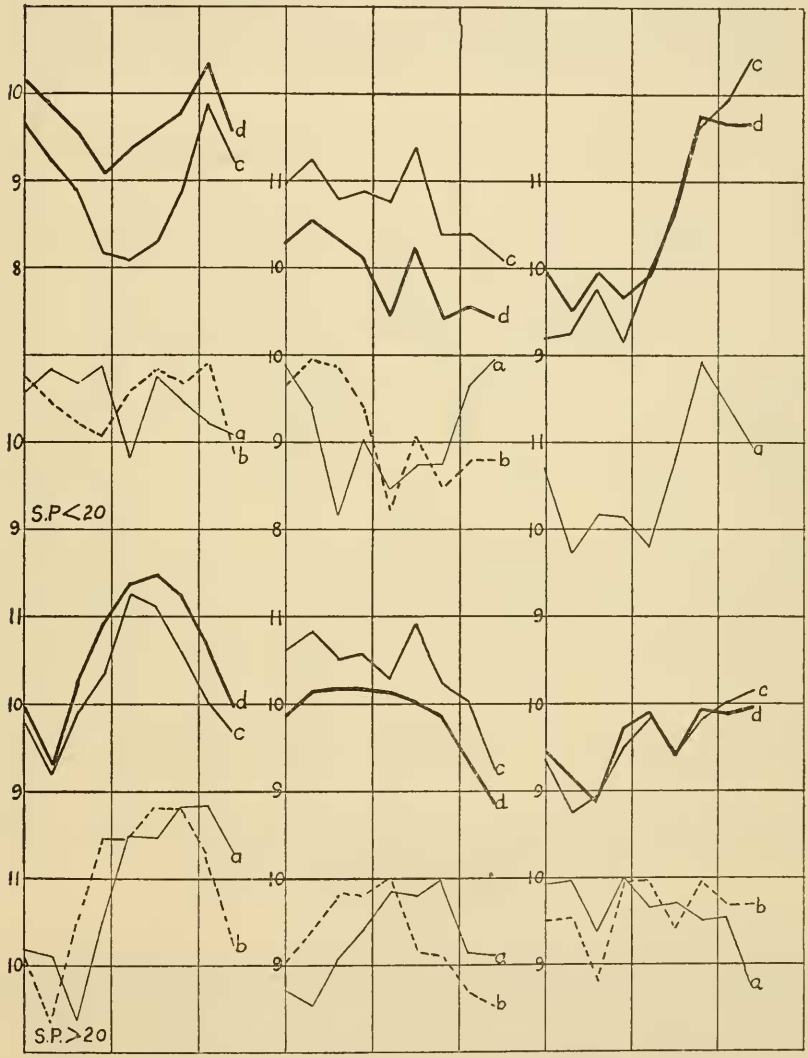
A_1						B_1								
Apr. '74	Feb. '78	Mar. '88	Jan. '97	Apr. '98	Mean	Feb. '02	Mar. '12	Jan. '21	Mar. '31	Apr. '98	Mean	$A_1\downarrow_5$	Mean	Δ
62	111	115	108	140	107.2	98	101	86	77	140	101.0	81.8	91.4	−10.4
54	97	102	105	113	94.2	89	108	121	85	113	106.8	89.4	98.1	− 3.7
83	115	121	108	98	105.0	118	124	112	110	98	111.0	103.2	107.1	+ 5.3
76	104	110	79	108	95.4	143	122	108	111	108	112.2	104.4	108.3	+ 6.5
79	123	126	92	103	104.6	144	95	122	120	103	105.0	110.4	107.7	+ 5.9
88	101	109	65	100	92.6	170	103	116	118	100	109.2	107.2	108.2	+ 6.4
80	109	122	54	107	94.4	188	106	96	145	107	113.5	94.2	103.8	+ 2.0
47	93	110	48	92	78.0	176	88	108	134	92	105.5	105.0	105.2	+ 3.4
65	100	114	67	84	86.0	153	103	126	147	84	115.0	95.4	105.2	+ 3.4
70	80	99	54	82	77.0	122	120	139	138	82	119.8	104.6	112.2	+10.4
65	86	92	93	73	81.8	101	113	131	131	73	112.0	92.6	102.3	+ 0.5
80	68	87	118	94	89.4	94	124	129	104	94	110.5	94.4	102.4	+ 0.6
95	81	82	157	101	103.2	98	122	142	99	101	113.5	78.0	95.7	− 6.1
113	64	100	157	88	104.4	104	110	137	76	88	102.7	86.0	94.3	− 7.5
106	70	135	165	76	110.4	105	77	130	80	76	90.8	77.0	83.9	−17.9
				94				115				Mean	101.8	

A_2							B_2								
Aug. '56	June '65	May '79	Aug. '80	June '89	July '75	Mean	Aug. '99	June '13	May '22	Aug. '23	June '32	Mean	$A_2\uparrow_2$	Mean	Δ
53	99	79	85	134	132	97.0	84	74	110	100	86	90.8	106.2	98.5	− 4.3
80	118	80	88	128	137	105.2	89	62	79	99	81	82.0	98.0	90.0	−12.8
107	121	78	81	125	125	106.2	101	77	67	114	87	89.2	107.2	98.2	− 4.6
101	115	90	65	111	106	98.0	116	87	60	115	86	93.8	115.3	104.5	+ 1.7
138	95	112	85	81	132	107.2	134	92	86	107	113	106.4	109.7	108.0	+ 5.2
153	109	112	95	107	116	115.3	123	95	83	92	111	100.8	109.8	105.3	+ 2.5
124	80	135	87	110	122	109.7	110	97	92	95	118	102.4	120.8	111.6	+ 8.8
95	83	158	96	111	116	109.8	116	85	87	81	126	99.0	111.2	105.1	+ 2.3
105	99	164	126	102	129	120.8	101	75	100	105	140	104.2	106.3	105.2	+ 2.4
71	104	155	101	102	134	111.2	58	79	81	119	132	93.8	104.5	99.1	− 3.7
80	79	170	85	81	143	106.3	88	58	93	150	118	101.4	107.3	104.3	+ 1.5
84	97	144	99	69	134	104.5	96	65	92	154	114	104.2	111.0	107.6	+ 4.8
88	109	119	122	68	138	107.3	90	79	91	154	101	103.0	115.0	109.0	+ 6.2
86	124	118	122	62	154	111.0	98	84	83	114	110	97.8	97.0	97.4	− 5.4
94	133	103	146	75	139	115.0	100	70	96	106	87	91.8	105.2	98.5	− 4.3
					110								Mean	102.8	

A_3						B_3								
Nov. '57	Sept. '66	Nov. '76	Sept. '85	Dec. '86	Mean	Nov. '00	Sept. '09	Dec. '10	Dec. '29	Sept. '33	Mean	$A_3\downarrow_5$	Mean	Δ
74	121	98	97	97	97.4	84	131	91	114	82	100.4	105.4	102.9	+10.6
82	112	75	102	87	91.6	85	132	97	90	83	97.4	106.8	102.1	+9.8
88	100	63	91	86	85.6	93	152	109	86	76	103.2	103.6	103.4	+11.1
111	100	59	81	83	86.8	80	149	101	87	55	94.4	109.0	103.2	+10.9
135	90	70	77	79	90.2	84	107	112	71	50	84.8	102.4	93.1	+ 0.8
148	97	103	83	50	96.2	85	93	99	54	56	77.4	97.4	87.4	− 4.9
159	98	120	72	64	102.6	94	90	94	53	45	73.2	91.6	82.4	− 9.9
156	98	112	84	67	103.4	73	70	114	41	50	69.6	85.6	77.6	−14.7
139	80	106	67	77	93.8	81	76	129	63	73	84.4	86.8	85.6	− 6.7
127	85	129	72	82	99.0	81	78	115	79	77	86.0	90.2	88.1	− 4.2
137	76	127	83	104	105.4	61	68	123	76	103	86.2	96.2	91.2	− 1.1
144	62	136	85	107	106.8	62	58	114	72	115	84.2	102.6	93.4	+ 1.1
138	62	127	78	113	103.6	59	61	89	75	141	85.0	103.4	94.2	+ 1.9
138	59	138	85	125	109.0	60	55	83	64	123	77.0	93.8	85.4	− 6.9
149	50	117	77	119	102.4	92	80	101	53	127	90.6	99.0	94.8	+ 2.5
												Mean	92.3	

lines, represents the first half of the interval. Along with it, in heavy dotted lines (*b*) appears the same curve, shifted in phase as indicated in the tabulation, tables 1 and 2. The medium-heavy full curve above (*c*) in each chart, gives the results tabulated for the second half of

the interval. The reader will perceive a considerable similarity in form between curves (*b*) and (*c*). Owing to the causes producing roughness in the mean results, as explained above, this correspondence



FIGS. 2 (lower) AND 3 (upper).—Graphs of the $9\frac{1}{16}$-month periodicity.

is not as close as one could wish. However, it is the best available, and mean curves in heavy lines are plotted in lines (*d*). Their general similarity to the curves (*c*) indicate that the first half of the data,

when in the same phase, supports the second-half determinations of the periodicity.

Amplitudes of Peoria periodicities.—The reader will note that all the curves (*d*) in figures 2 and 3 indicate an amplitude for the $9\frac{1}{6}$-month periodicity of above 10 percent and several of them above 20 percent. Of the 19 periodicities determined in Peoria precipitation, none have a less average amplitude than 5 percent, and 10 of them

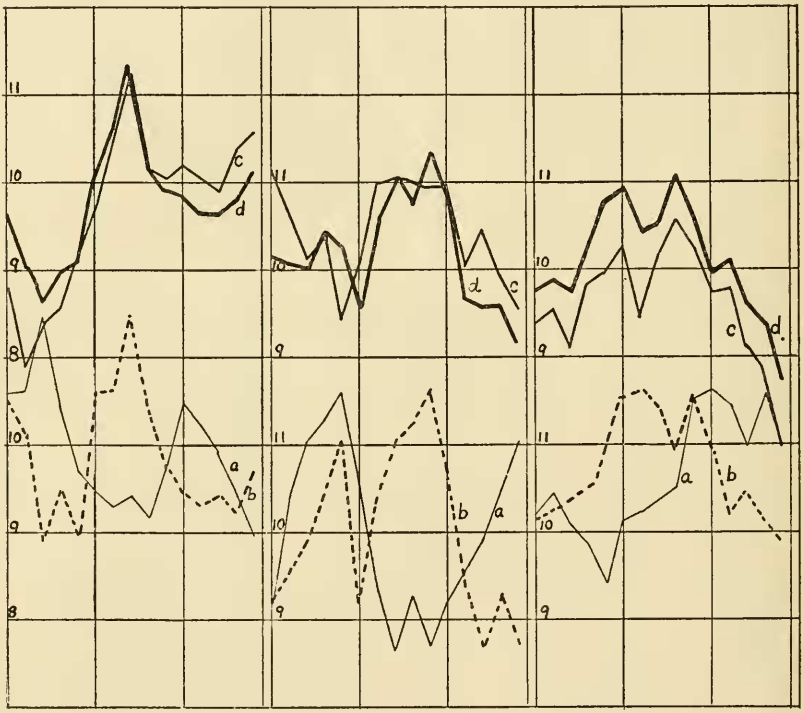


Fig. 4.—Graphs of the $15\frac{1}{6}$-month periodicity.
Wolf numbers > 20.

exceed 20 percent in average amplitude. This may seem extraordinary to those who recall that the solar variations which control these periodicities in precipitation, as recorded in the paper cited above, seldom had amplitudes as great as 0.2 percent. But the explanation is not as yet susceptible to theory; we have to accept the results of tabulations.

Figures 4 and 5, suited to Wolf numbers $\gtrless 20$ for the periodicity of $15\frac{1}{6}$ months, will be understood from the preceding description, relating to $9\frac{1}{6}$ months. It will be noted that in figures 4 and 5 the amplitudes of the curves (*d*) are in all cases about 20 percent.

Forecasts of precipitation for future years.—The reader will perceive that since the periodicities fixed by tabulations of Peoria precipitation employ only data of the years 1856 to 1939, it is perfectly justified to use them to predict from a synthesis the precipitation expected to be observed at Peoria in the years 1940 to 1950. This operation has been performed. The data for it are such as given in the columns Δ of tables 1–4.

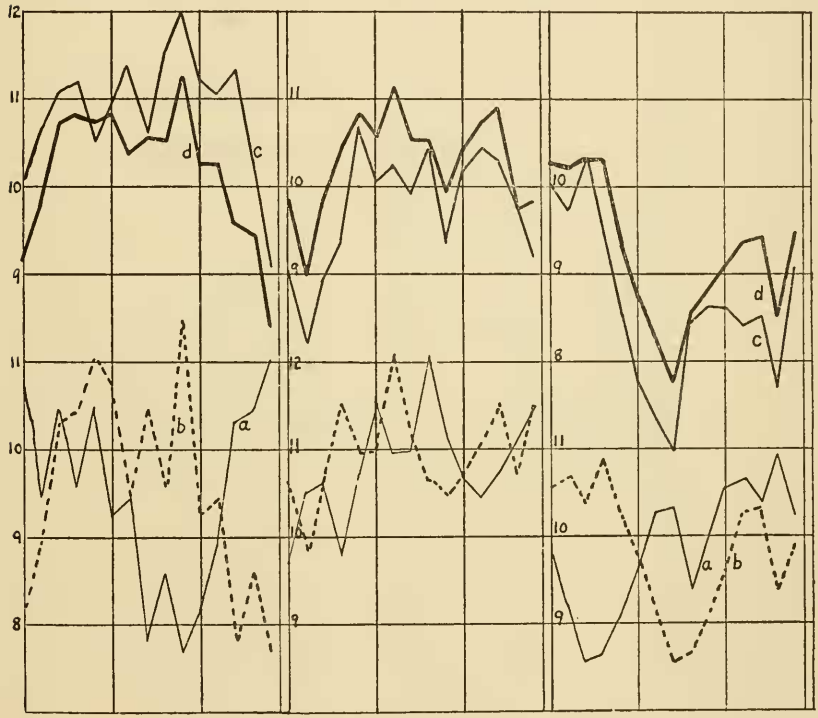


FIG. 5.—Graphs of $15\frac{1}{6}$-month periodicity.
Wolf numbers < 20.

To fix ideas, there is given in table 5 as much of this tabulation as covers the years 1940 and 1950. The summation of the 19 columns purports to show for these future years what will be the percentage departures from the normals that were printed above. In the next to final column of table 5 are given the actual observed departures from those normals, computed from Weather Bureau records. The final column gives the percentage differences between predicted and observed. The reader will recall that all these data were smoothed by 5-month consecutive means before the tabulation.

TABLE 5.—*Sample of synthesis prediction and verification*

Percentages in tenths of percent
Sums given to nearest percent

	$4\frac{1}{3}$	$5\frac{1}{8}$	$6\frac{1}{15}$	7	$8\frac{1}{8}$	$9\frac{1}{8}$	$9\frac{3}{4}$	$10\frac{3}{5}$	$11\frac{1}{5}$	$13\frac{1}{10}$	$13\frac{3}{8}$	$15\frac{1}{8}$	$22\frac{1}{8}$	$24\frac{1}{8}$	$30\frac{1}{8}$	$34\frac{1}{5}$	$38\frac{1}{8}$	$45\frac{1}{2}$	$91\frac{1}{2}$	Σ	Obs	Δ
1940																						
Jan.	+12	−23	−21	+27	+21	− 59	− 12	+ 7	+ 3	−45	+ 68	− 20	−18	−39	− 6	− 19	+ 3	− 65	− 99	−28	−50	+22
Feb.	−28	−13	− 8	+68	+ 1	−125	− 20	+ 52	−43	−34	+ 65	− 81	+27	−36	−28	− 20	+22	− 54	− 94	−35	−39	+ 4
Mar.	− 1	−34	+33	+19	+ 1	− 35	+ 10	+ 48	−39	− 3	+ 24	−120	+ 5	−13	−52	− 22	+ 2	− 34	− 88	−30	−27	− 3
Apr.	+19	− 6	+35	−18	+15	+ 38	+ 49	+100	−22	+31	+ 32	− 86	+ 8	−26	−66	− 6	−36	− 19	− 79	− 4	−20	+16
May	+10	+32	− 6	−16	+45	+ 81	+ 57	+ 73	−47	+31	− 29	− 73	+52	+ 8	−30	− 59	−36	+ 22	− 69	+ 5	−26	+31
June	+26	+35	−31	−61	+25	+ 91	− 26	+ 2	−61	+53	− 47	+ 29	+35	−68	−27	− 28	−35	− 20	− 59	−17	−20	+ 3
July	−28	−17	−10	−21	−46	+ 62	+ 28	− 24	+33	+56	− 65	+ 72	+49	−75	−40	− 60	−21	+ 2	− 49	−15	−35	+20
Aug.	− 9	− 2	−10	+14	−58	+ 8	0	− 27	+ 9	0	− 51	+153	+81	−89	−18	− 53	− 9	+ 22	− 42	− 8	−25	+17
Sept.	± 0	−23	+13	+34	+90	− 61	− 41	− 61	+83	−55	−114	+ 44	+10	−50	−57	+ 8	−19	+ 53	− 31	−17	−25	+ 8
Oct.	+ 9	0	+29	+27	+17	+ 2	− 48	− 92	+36	+11	− 72	+ 3	−22	−75	+ 1	+ 68	−19	+ 62	− 19	− 8	−10	+ 2
Nov.	−31	+ 6	− 2	+12	−31	− 21	+102	− 83	+45	− 1	− 8	0	−51	− 6	− 6	+ 84	−23	+ 60	− 14	+ 3	+ 7	− 4
Dec.	+23	+17	−10	+13	−48	− 39	+ 74	+ 25	+66	−31	+ 16	− 16	−76	+ 5	+40	+114	−56	+ 70	− 5	+18	+11	+ 7
1950																						
Jan.	− 1	−34	−21	+18	−84	− 21	− 74	− 74	+36	+52	+ 16	− 74	+49	+10	+27	− 1	+ 2	+125	+106	+ 6	+29	−23
Feb.	+12	− 6	− 8	+24	−76	− 39	− 77	− 84	+45	+54	+ 77	−141	+81	−48	− 6	+ 30	−36	+ 55	+111	− 3	+50	−53
Mar.	−28	+32	+33	+17	+21	+ 16	− 43	− 27	+ 3	+24	+ 68	− 20	+10	−43	−28	+ 63	−36	+ 25	+112	+19	+23	− 4
Apr.	− 1	+35	+35	+ 8	+ 1	+ 18	0	− 1	−43	+21	+ 65	− 81	−22	−17	−52	+ 31	−35	+ 16	+110	+ 9	+13	− 4
May	+19	−17	− 6	−25	+ 1	− 2	+ 6	+ 20	−39	−22	+ 24	−120	−51	−39	−66	+ 1	−21	0	+106	−29	+ 6	−35
June	+14	− 2	−31	−20	+15	+ 10	+ 13	+ 58	−22	−25	+ 32	− 86	−76	−36	−30	− 26	− 9	− 42	+104	−16	+ 5	−21
July	+10	−23	−10	+14	+45	+ 25	+ 1	+ 78	−47	−49	− 29	− 73	−80	−13	−27	− 80	−19	− 62	+ 96	−24	−10	−14
Aug.	+26	0	−10	+34	+25	− 10	− 4	+ 22	−61	−18	− 47	+ 29	−25	−26	−40	−113	−19	− 63	+ 76	−22	−12	−10
Sept.	−28	+ 6	+13	+27	−46	+ 2	− 10	+ 28	+33	−59	− 65	+ 72	−19	+ 8	−18	− 75	−23	− 70	+ 16	−21	−24	+ 3
Oct.	− 9	+17	+29	+12	−58	− 21	− 56	+ 22	+ 9	−76	− 51	+153	+25	−68	−57	− 38	−56	− 97	− 36	−36	−37	+ 1
Nov.	+ 9	+ 2	− 2	+13	+90	− 39	− 35	+ 24	+83	−36	−114	+ 44	+10	−75	+ 1	− 7	−55	− 69	− 99	−22	+26	−48
Dec.	−31	+24	− 2	−25	+17	+ 16	+ 13	+ 30	+36	+ 4	− 72	+ 3	−16	−89	− 6	− 7	− 5	− 83	−104	−23	+36	−59

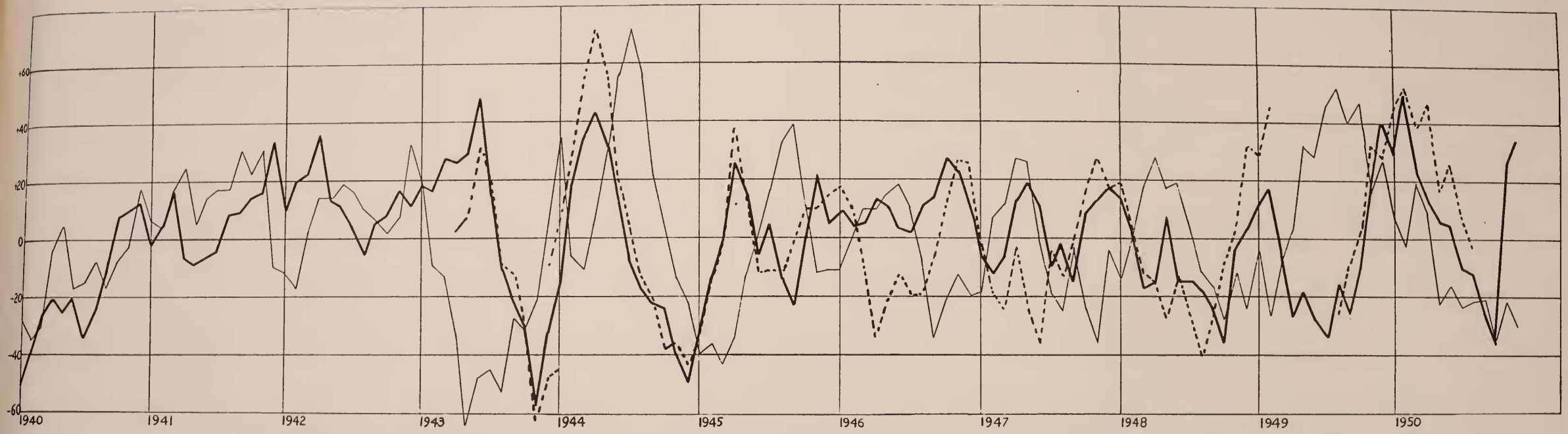


Fig. 6.—Predicted precipitation at Peoria, Ill., 1940 to 1950, and verification. Prediction based on sun's variation as determined in Smithsonian Publ. 4088. Thin line is prediction, thick line is event. Dotted line is prediction altered in phase as stated in text. All curves from 5-month running means.

Graphical comparison of forecast and event.—In figure 6 the whole march of the synthetically forecasted expected departures from normal precipitation at Peoria from 1940 to 1950 are plotted along with the actual departures observed. The reader will still recall that the data were smoothed by 5-month running means before any tabulating was done.

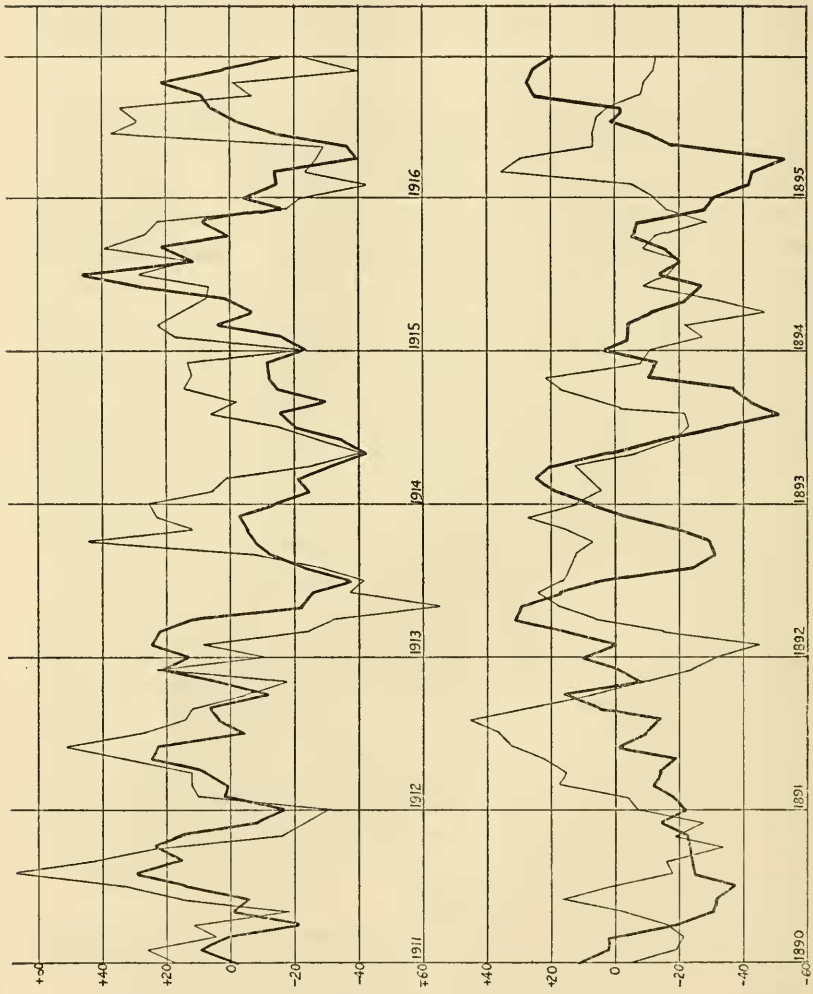
Fit of the curve of prediction.—For 3 years, 1940 to 1942, there is fair agreement between prediction and event. The average divergence between the two curves for 37 months is 13.9 percent. This is quite as close an agreement between prediction and synthesis of periodicities as obtained in the years prior to 1940, when, as one might say, the curves are "tailored to fit." Illustrations of this are given in figures 7 and 8, which deal with the intervals 1890 to 1895 and 1911 to 1916.

Phase changes.—After 1942 came changes of phase, but not of form. Heavy dotted curves are drawn in figure 6 to show the great similarity of form of the two curves when certain changes of phase are permitted. From October 1942 to July 1943 the predicted curve is moved forward 6 months. From March 1944 to June 1945 the predicted curve is moved backward 3 months. Thereafter, for the long interval extending until July 1949, the predicted curve is moved backward bodily 6 months. Finally, from February 1949 to February 1950 the predicted curve is moved forward 6 months.

With these changes of phase admitted, the two curves show for 81 months after 1942 an average divergence between them of 15 percent. Adding the first 3 years, which showed 35 months of fairly close fit, prediction would agree with event for 116 months out of 132, with an average divergence of 15 percent, though including several large swings of from 70 to 90 percent in amplitude. With such a good measure of success an 11-year prediction of precipitation at Peoria would confront us, though based on solar variation alone with no recourse to meteorology, if the several phase changes above suggested could be understood and anticipated.

Taking no consideration whatever of phase changes, the average departure between prediction and event is 14.7 percent for 99 months out of 136. Large divergences occur in the other 37 months.

Quality of representation.—To throw light, if possible, on phase changes, and to expose the roughness of the representation of precipitation by syntheses of periodicities as it stands before attempting a prediction, owing to causes already discussed, two intervals of curves of synthesis and observation prior to 1940 are shown in figures 7 and 8. The intervals chosen are from 1890 to 1895 and from 1911 to 1916. The synthetic curve in figure 7 is at a disadvantage, compared to that



FIGS. 7 (lower) AND 8 (upper).—Comparisons of synthesis with event in years prior to 1940. See comments in text.

in figure 8, because, as stated above, all the mean values from tabulations of the first half of the data were shifted in phase as required to match the phases of the mean values of data of the second half. Hence the general mean used for the syntheses is not so well suited to the first half of the 84-year interval as to the second half.

This disadvantage shows plainly, for figure 7 shows less good agreement than figure 8, yet a considerable part of the curves in figure 7 show fair correspondence. What is particularly interesting in figure 7 is that several cases of phase shifting, similar to those noted above in figure 5, are obvious. Such shiftings appear in the years 1890, 1892, 1893, and notably in 1895. One clearly marked phase shift is seen in the year 1913, in figure 8, and a lesser one in the year 1916.

The reader will see, by comparing figures 7 and 8, which relate to years employed for computing the data for prediction, with figure 6, where the basic periodicities were used for forecasting, that the "tailored to fit" curves, figures 7 and 8, agree no better, if indeed quite as well, with observation as the predicted curve agrees with the event in figure 6.

Solar variation controls weather.—The outcome of this attempt to forecast precipitation for a decade in advance by knowledge of periodicities in solar variation, without recourse to meteorology, is somewhat disappointing because of the phase changes encountered. It had been hoped that forecasts of percentage precipitation for coming seasons over a 10-year interval to within 10 or 15 percent might be made. If this could be done for one station, perhaps it might also be done for many. Then a network of lines of equal percentage precipitation for coming seasons for several years in advance might be laid down on the map. Possibly meteorologists, if they take interest in the idea, may find some means to conquer the phase-changing obstacle, and realize this dream of long-range seasonal forecasts.

Hitherto, for 40 years there has been a reluctance on the part of scientists, and especially meteorologists, to recognize the reality of observed changes of solar radiation. Even if it were admitted that very small solar changes occur, they were thought by these scientists to be insignificant for weather. As one said: "If a room be lighted with 100 lamps, and one is extinguished, no one could notice the loss of illumination." This paper, and Smithsonian Publ. 4088, indicate a contrary conclusion.

SUMMARY

I have sought, in a preceding paper cited above (footnote 1) to demonstrate the reality of 23 periodic changes in the intensity of the

solar rays that warm the earth. In this present paper it is shown that periodicities of the same length as 19 of those discovered in solar variation are accompanied by changes of 5 to 20 percent amplitude in the precipitation at Peoria, Ill. By samples graphed in figures 2, 3, 4, 5, and in no way unrepresentative of all the periodicities tabulated, it is shown that these periodic variations of precipitation occur in nearly equal amplitudes and with moderate differences of phase in 12 separate independent intervals, each several years long, between 1856 and 1939.

Using these results as a basis, I predict the precipitation for Peoria from 1940 to 1950. With a range of actual precipitation from 50 to 150 percent of normal, occurring in that interval in the smoothed records, prediction matches the event for 8 out of 11 years to within an average deviation of 14.7 percent. In the other 3 years, large fluctuations in actual precipitation were matched by strikingly similar large fluctuations in the curve of prediction, but with phase differences of from 3 to 6 months. The prediction matches the event as well after 10 years as at the beginning. The fluctuations in the curve of prediction have almost precisely the same scale of range as those in the curve of actual precipitation.

While it is difficult to conceive, theoretically, how solar changes, seldom as large as 0.2 percent, could produce variations of from 5 to 20 percent in precipitation, the facts are there. It may be that adequate theory will eventually be found to explain them. In the meantime it would be of no importance, practically, whether theory had overtaken fact, if it were found that these periodic changes of precipitation could be synthesized to forecast seasons for years in advance.

A partial success in that direction has been achieved. For 3 years in advance the curve of prediction shown in figure 6 follows generally a rise of actual precipitation amounting to 90 percent. For 99 months out of 136, indeed, the average divergence is 15 percent. But the long-range prediction is marred by changes of phase, which, thus far at least, cannot be anticipated and allowed for in advance.

To the interested general reader, unfamiliar perhaps with considering percentages of normal precipitation, the meat of the matter may be expressed as follows: A prediction for 11 years in advance, based on knowledge of the sun's variation, without any consideration of meteorology, fits the rainfall curve at Peoria, Ill., for 99 months out of 136, to within an average error of one medium rainfall per month, or about 0.4 of an inch per month. Sometimes, however, dry or wet spells occur 3 to 6 months from when they are expected. Unless these phase changes can be anticipated, the method fails to come up fully to what is hoped for.